United States
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Economic Research Service
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and
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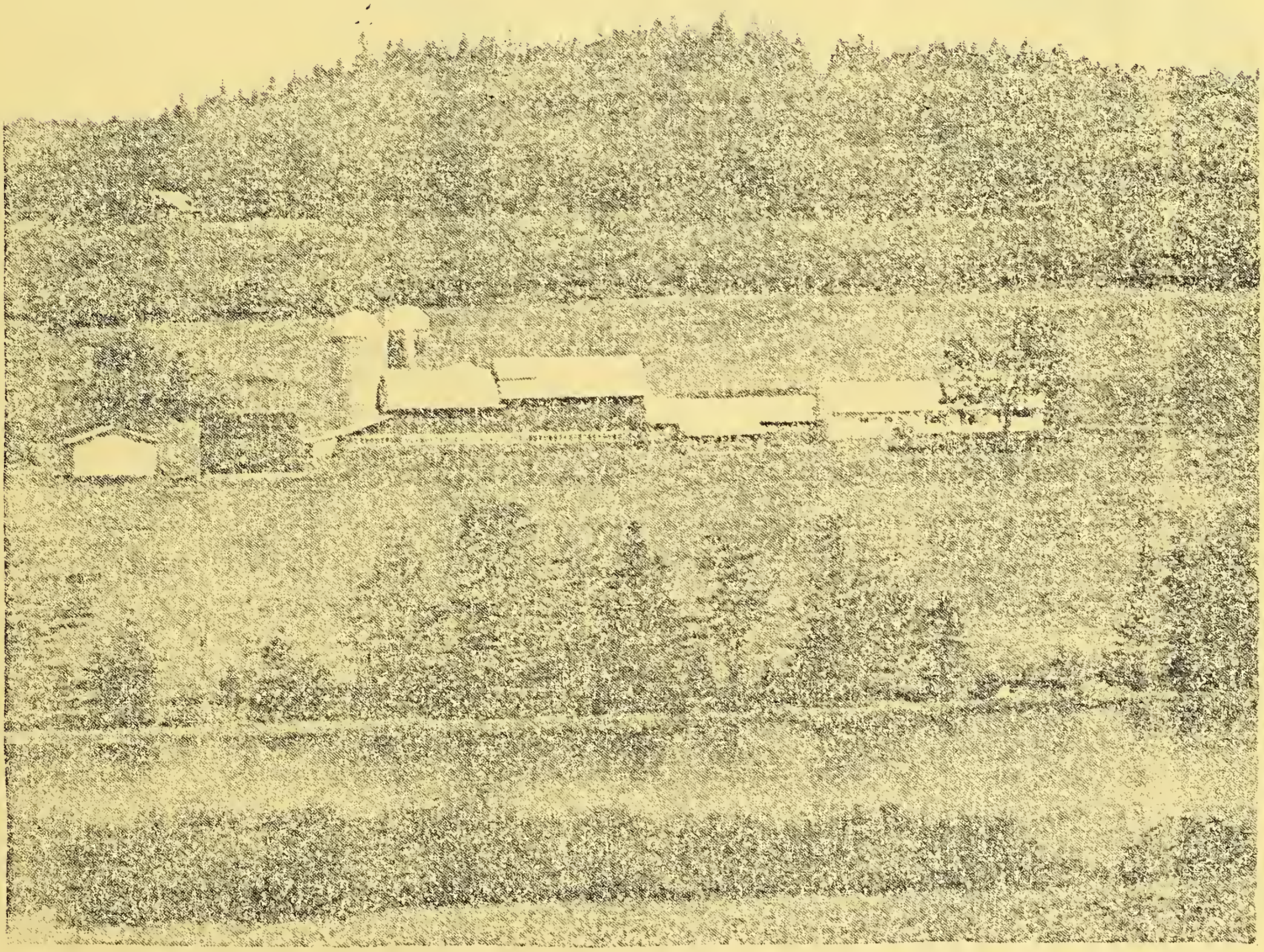
EROSION AND SEDIMENT PRODUCTION FROM LOGGING ROADS IN VERMONT

A technical report of the Agricultural Runoff in Selected Vermont Watersheds Study



November 1982

EROSION AND SEDIMENT PRODUCTION FROM LOGGING ROADS IN VERMONT

Technical Report

Agricultural Runoff in Selected Vermont Watersheds Study

U. S. Department of Agriculture

Economic Research Service
Forest Service
Soil Conservation Service

In cooperation with

State of Vermont

Agency of Environmental Conservation
Department of Agriculture

Forest Service
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

A field survey of erosion and sedimentation from 45 logging sites[1] was conducted as part of the USDA Cooperative Study "Agricultural Runoff from Selected Vermont Watersheds". A modification of the Universal Soil Loss Equation was used to estimate soil loss from the roads and landings of the harvest sites, and to estimate the delivery of sediment to stream channels. The sampling effort was focused on the road system because such areas are the origin of virtually all sediment from eastern forests. The methodology is described in detail, and examples given of field data and its analysis.

Results showed that the road systems of 19 of the 45 sites (42%) were eroding in excess of the SCS tolerable rate of soil loss of 3 tons/acre/year. When the data were averaged by watershed, ten of the 15 sampled watersheds had erosion rates on the road systems greater than 3 tons/acre/year. Erosion rates from the harvested areas as a whole, road and non-road portions, were considerably lower, ranging from 0.11 to 0.41 ton/acre/year. Eroded soil from roads and landings reached active water channels on 31 of the 45 sites (69%). Average annual sedimentation rates ranged from 0.2 to 4.6 tons/acre/year, while total tons of sediment delivered by the road systems per year ranged from 0.1 to 9.6 tons.

High erosion rates were associated with mountainous topography and steep road grades (in excess of 10%). Harvest sites receiving technical assistance from a county forester averaged 3.4 tons/acre/year in erosion from the road system, whereas similar sites with assistance from a private consultant averaged 6.2 tons/acre/year and with no assistance (logger's choice) 7.0 tons/acre/year from the roads. The county foresters indicated that they usually flag the major roads for a sale in addition to marking timber, which may account for the lower erosion rate on such sites.

Erosion from timber harvesting can be kept at the normal rate for undisturbed forests by using the following measures in road construction:

1) Plan the road system before harvesting
2) Keep road gradients below 10%
3) Locate roads away from streams
4) Provide good drainage on roads
5) Maintain the usefulness of the roads after harvest by stabilizing them (putting the road "to sleep")

The landowner is the key to insuring that the logger follows these guidelines. The roads are a capital investment by the landowner that provide him with present and future access to his property for timber, fuelwood, recreation, etc. Informing and educating forest landowners about the benefits derived from protecting their investment in roads will also help to minimize non-point pollution from forestry activities in Vermont.

[1]/Harvey's Lake Watershed was added to the study after the field work was completed in Fall 1980. It was surveyed in June 1981, and is analyzed in Appendix A.

INTRODUCTION

The forested lands of Vermont are one of the State's most important natural resources. Historically, the forests have provided useful amenities such as timber, fuel, water, game, and in more recent years, recreation and aesthetic enjoyment. The production of clean, high quality water from forested lands can be adversely affected by careless pursuit of the other forest commodities. The increase in demand for water created by projected population growth in the Northeast requires that forests be managed and utilized so as to protect the water resource.

This report is an assessment of the impact of silvicultural activities on water quality on 18 Vermont watersheds. A field survey of erosion and sedimentation generated by timber harvest roads was conducted as part of the Forest Service contribution to the USDA Cooperative Study "Agricultural Runoff from Selected Vermont Watersheds." The results of the study are presented in this report, and their significance and implications discussed.

PROCEDURE

Locating Logging Sites

Harvested areas in the study watersheds were located by three methods. First, in August 1980, logged areas were sighted from the air, and their locations marked on aeronautical charts. The positions of these sites were then transferred to USGS topographic quadrangles (7 1/2' and 15' quads). The second means of locating cut areas was through interviews with county foresters of the Department of Forests and Parks. The third method was on-the-ground sighting during the erosion survey. The county foresters also supplied information on the level of technical assistance employed by the landowners of all sites surveyed.

Field Procedure

The field procedure for determining erosion and sedimentation rates is a modification of the method developed by the Vermont Department of Forests and Parks in cooperation with the U.S.D.A. Soil Conservation Service and the Forest Service. This method is described in "Non-Point Source Water Pollution Handbook", January 1975. Recognizing that 99% of sediment in eastern forests originates on logging roads (Hartung and Kress, 1977), the procedure was modified to evaluate only the road system and landing areas, rather than the entire harvested area.

Equipment needed for this erosion survey was a means of measuring slope such as a clinometer or Abney level, compass, clipboard, and data sheets. After a logging job was located on the ground, the main skid road was walked into the harvested area. Based on the size of the cut area and road system, a systematic distance between sample points, i.e. 50 paces, 100 paces, was chosen. Starting at the end of one of the major skid roads, sample points were located by pacing. Upon reaching a sample point, the following evaluations were made:

1) Type of road: skid trail, skid road, landing, log road. A log road is defined as the road connecting the landing to a permanent, public road. This road is used primarily by log trucks. The landing is the area in which logs brought in by skidder are sorted and loaded. The skid road is the major route from skid trails to the landing. A skid trail branches off the skid road to the tree, and is customarily traversed by a skidder only a few times. However, in order for a skid trail to be included in the survey, some mineral soil must have been exposed during the logging operation.

2) The length of the road segment on which the sample point falls. The road segment is defined to be from the point where overland flow would begin to the point of deposition or where flow leaves the road.

3) Percent canopy cover over the road segment, whether tree, shrub, or grass.

4) Effective canopy height to mid crown. In a situation where there is a multi-layered canopy, the layer which is most effective at intercepting precipitation is used. In practice, the most effective layer is usually taken to be the most extensive canopy cover under ten meters in height.

5) Percent root network, which is an evaluation of the infiltration potential of the road surface compared to the undisturbed forest floor. This parameter encompasses root and organic matter content, soil structure and porosity.

6) Percent bare and percent protected ground, which are determined by pacing the road segment, and scoring each pace as "protected" if the soil is covered by rock, duff or sod, and "bare" if mineral soil is exposed with particle sizes of less than 3/4 inch along any one axis.

7) Percent slope for the road segment is measured, and length and width estimated.

8) In order to estimate the amount of eroded material reaching a channel, the distance and slope from the bottom of the road segment to the nearest functioning channel (if any) is determined.

Figure 1 is the data sheet used for recording the above information. At the top, the watershed number, and site number (each logging site was numbered consecutively as it was surveyed) are entered, as are the type of ownership (private, state, federal) and the party responsible for road layout (logger, county forester, private consultant). The first column contains the road type (ST = skid trail, SR = skid road, L = landing, LR = log road); the second column indicates the systematic spacing between sample points; and the third column is the sample point number. Columns 4 and 5 record the number of paces with bare or protected ground, respectively; columns 6, 7 and 8 contain the percent slope, length and width of the road

Watershed No. ________ Site No. ________ Ownership ________ Road Layout ________ Date ________

					Sample			Sample to Channel										Sample			Sample to Channel				
Road Type (1)	# Paces btwn Samples (2)	Sample No. (3)	No. Paces w/ Bare Ground (4)	No. Paces w/ Protected Grnd (5)	% Slope (6)	Length (ft) (7)	Width (ft) (8)	% Slope (9)	Length (ft) (10)	% Canopy Cover (11)	Eff. Canopy Ht. (M) (12)	% Root Network (13)	Road Type	# Paces btwn Samples	Sample No.	No. Paces w/ Bare Ground	No. Paces w/ Protected Grnd	% Slope	Length (ft)	Width (ft)	% Slope	Length (ft)	% Canopy Cover	Eff. Canopy Ht (in)	% Root

Figure 1. Field data sheet for erosion and sedimentation survey.

segment; columns 9 and 10 record the percent slope and distance from the bottom of the road segment to the channel; columns 11, 12, and 13 record percent canopy cover, effective canopy height, and percent root network, respectively. These thirteen columns are duplicated on the second half of the page.

A sketch map of the road system, using the compass for proper orientation, was made on the back of the data sheet. A general description of the area, type of cutting, possible time since harvest, and any other information available was also recorded on the back.

DATA ANALYSIS

Erosion

The Universal Soil Loss Equation was developed by Wischmeier and Smith (1965) for estimating average annual erosion rates on agricultural lands. This empirical model has been modified for application to forestlands (Wischmeier, 1972). At each sample point on a logging site, the Modified Soil Loss Equation (MSLE) was used to estimate the average annual erosion rate:

$$A = (R) \times (K) \times (LS) \times (VM) \qquad \text{(Eq. 1)}$$

Where

A = estimated soil loss due to sheet and rill erosion, in tons per acre per year.

R = rainfall factor, or the erosive potential of rainstorms in the area. The value for R is obtained by linear interpolation on an isoerodent map (Figure 2).

K = soil erodibility, or the inherent susceptibility of a particular soil to erode, based on its physical properties alone. The value for K is obtained from a published soil survey, or from a soil scientist knowledgeable about the soils of the study area.

LS = topographic factor for slope gradient and length. The LS factor for gradients up to 60% and lengths to 2000 feet is obtained from Figure 3. Similar information is tabulated in Table 1. Slope length of the sampled road segment is defined to be the length of overland flow from the point of origin to the point where the slope changes sufficiently to cause sediment deposition, or where the flow leaves the road, whichever limits the length.

VM = vegetation-management factor, which evaluates the effects of vegetative cover and silvicultural activities on erosion. (This factor replaces C, the cropping factor, and P, the erosion control practice factor in the original Universal Soil Loss Equation). VM is evaluated as a combination of 3 subfactors:

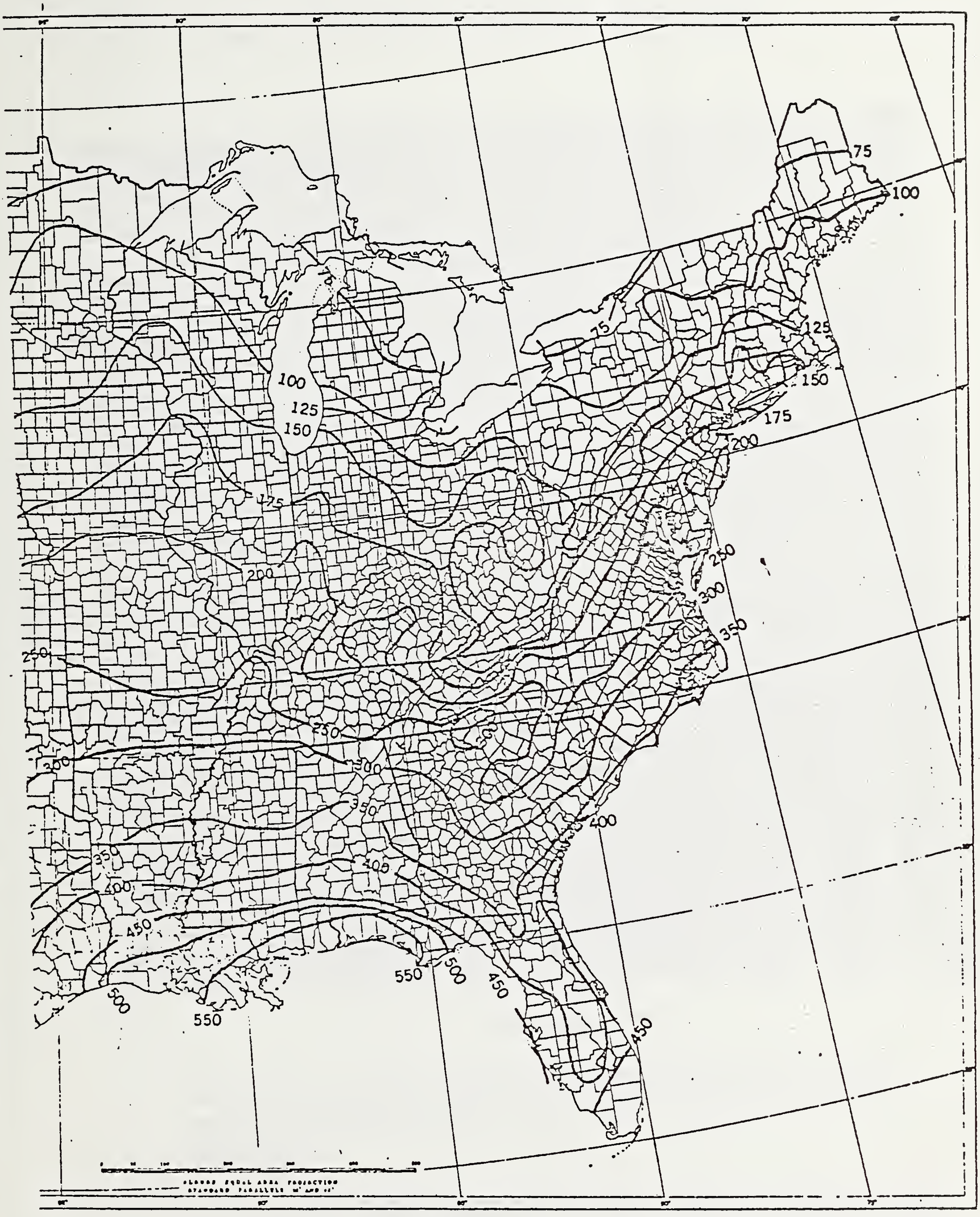
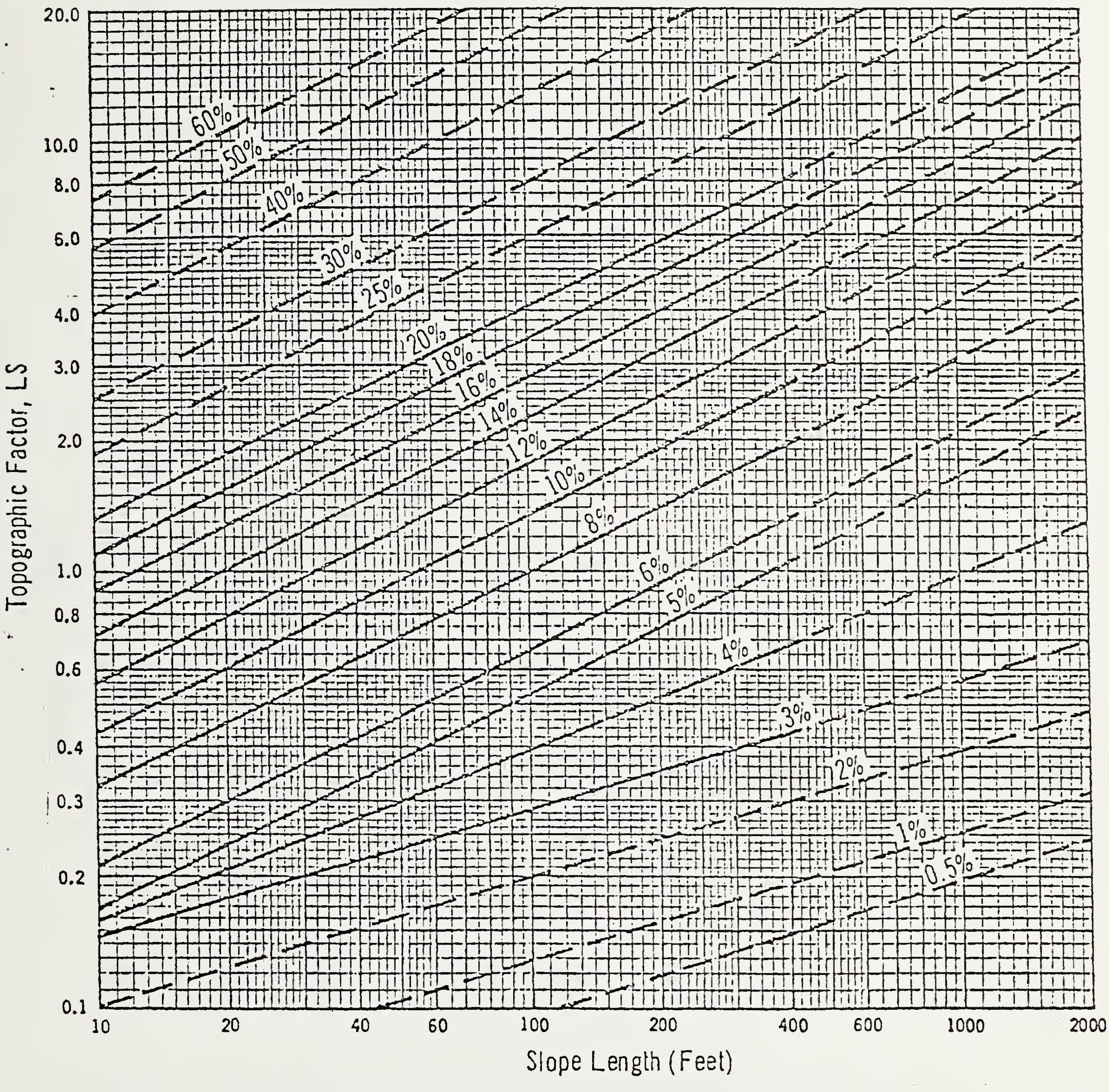


Figure 2. Iso-erodent map illustrating average annual values of the rainfall factor, R

From: US EPA. 1980. An approach to water resources evaluation of non-point silvicultural sources (A procedural handbook). EPA-600/8-80-012

Figure 3 SLOPE-EFFECT CHART (Topographic Factor, LS)*



*The dashed lines represent estimates for slope dimensions beyond the range of lengths and steepnesses for which data are available. The curves were derived by the formula:

$$LS = \left(\frac{\lambda}{72.6}\right)^m \left(\frac{430x^2 + 30x + 0.43}{6.57415}\right)$$

where λ = field slope length in feet and m = 0.5 if s = 5% or greater, 0.4 if s = 4%, and 0.3 if s = 3% or less; and x = sin θ. θ is the angle of slope in degrees.

From: USDA Soil Conservation Service. 1975. Procedure for computing sheet and rill erosion on project areas. Tech. Release No. 51 (rev.).

Table 1 Slope-Effect Table (Topographic Factor, LS)

Percent Slope	Slope Length in Feet 10	20	40	60	80	100	110	120	130	140	150	160	180	200
0.2	0.04	0.05	0.06	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.10	0.10
0.3	0.04	0.05	0.07	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11
0.4	0.05	0.06	0.07	0.08	0.09	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11
0.5	0.05	0.06	0.08	0.08	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.12	0.12
1.0	0.06	0.08	0.10	0.11	0.12	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.15	0.16
2.0	0.10	0.12	0.15	0.17	0.19	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.25
3.0	0.14	0.18	0.22	0.25	0.27	0.29	0.30	0.30	0.31	0.32	0.32	0.33	0.34	0.35
4.0	0.16	0.21	0.28	0.33	0.37	0.40	0.42	0.43	0.44	0.46	0.47	0.48	0.51	0.53
5.0	0.17	0.24	0.34	0.41	0.48	0.54	0.56	0.59	0.61	0.63	0.66	0.68	0.72	0.76
6.0	0.21	0.30	0.43	0.52	0.60	0.67	0.71	0.74	0.77	0.80	0.82	0.85	0.90	0.95
8.0	0.31	0.44	0.63	0.77	0.89	0.99	1.04	1.09	1.13	1.17	1.21	1.25	1.33	1.40
10.0	0.43	0.61	0.87	1.06	1.23	1.37	1.44	1.50	1.56	1.62	1.68	1.73	1.84	1.94
12.0	0.57	0.81	1.14	1.40	1.61	1.80	1.89	1.98	2.06	2.14	2.21	2.28	2.42	2.55
14.0	0.73	1.03	1.45	1.78	2.05	2.29	2.41	2.51	2.62	2.72	2.81	2.90	3.08	3.25
16.0	0.90	1.27	1.80	2.20	2.54	2.84	2.98	3.11	3.24	3.36	3.48	3.59	3.81	4.01
18.0	1.09	1.54	2.17	2.66	3.07	3.43	3.60	3.76	3.92	4.06	4.21	4.34	4.61	4.86
20.0	1.29	1.82	2.58	3.16	3.65	4.08	4.28	4.47	4.65	4.83	5.00	5.16	5.47	5.77
25.0	1.86	2.63	3.73	4.56	5.27	5.89	6.18	6.45	6.72	6.97	7.22	7.45	7.90	8.33
30.0	2.52	3.56	5.03	6.16	7.11	7.95	8.34	8.71	9.07	9.41	9.74	10.06	10.67	11.25
40.0	4.00	5.66	8.00	9.80	11.32	12.65	13.27	13.86	14.43	14.97	15.50	16.01	16.98	17.90
50.0	5.64	7.97	11.27	13.81	15.94	17.82	18.69	19.53	20.32	21.09	21.83	22.55	23.91	25.21
60.0	7.32	10.35	14.64	17.93	20.71	23.15	24.28	25.36	26.40	27.39	28.36	29.29	31.06	32.74

Table 1 Continued

Percent Slope	Slope Length in Feet 300	400	500	600	700	800	900	1000	1100	1200	1300	1500	1700	2000
0.2	0.11	0.12	0.13	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.18	0.19	0.19	0.20
0.3	0.12	0.13	0.14	0.15	0.16	0.16	0.17	0.18	0.18	0.18	0.19	0.20	0.21	0.22
0.4	0.13	0.14	0.15	0.16	0.17	0.17	0.18	0.19	0.19	0.20	0.20	0.21	0.22	0.23
0.5	0.14	0.15	0.16	0.17	0.18	0.18	0.19	0.20	0.20	0.21	0.21	0.22	0.23	0.24
1.0	0.18	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.27	0.28	0.29	0.30	0.32
2.0	0.28	0.31	0.33	0.34	0.36	0.38	0.39	0.40	0.41	0.42	0.43	0.45	0.47	0.49
3.0	0.40	0.44	0.47	0.49	0.52	0.54	0.56	0.57	0.59	0.61	0.62	0.65	0.67	0.71
4.0	0.62	0.70	0.76	0.82	0.87	0.92	0.96	1.01	1.04	1.08	1.12	1.18	1.24	1.33
5.0	0.93	1.07	1.20	1.31	1.42	1.52	1.61	1.69	1.78	1.86	1.93	2.07	2.21	2.40
6.0	1.17	1.35	1.50	1.65	1.78	1.90	2.02	2.13	2.23	2.33	2.43	2.61	2.77	3.01
8.0	1.72	1.98	2.22	2.43	2.62	2.81	2.98	3.14	3.29	3.44	3.58	3.84	4.09	4.44
10.0	2.37	2.74	3.06	3.36	3.62	3.87	4.11	4.33	4.54	4.74	4.94	5.30	5.65	6.13
12.0	3.13	3.61	4.04	4.42	4.77	5.10	5.41	5.71	5.99	6.25	6.51	6.99	7.44	8.07
14.0	3.98	4.59	5.13	5.62	6.07	6.49	6.88	7.26	7.61	7.95	8.27	8.89	9.46	10.26
16.0	4.92	5.68	6.35	6.95	7.51	8.03	8.52	8.98	9.42	9.83	10.24	11.00	11.71	12.70
18.0	5.95	6.87	7.68	8.41	9.09	9.71	10.30	10.86	11.39	11.90	12.38	13.30	14.16	15.36
20.0	7.07	8.16	9.12	9.99	10.79	11.54	12.24	12.90	13.53	14.13	14.71	15.80	16.82	18.24
25.0	10.20	11.78	13.17	14.43	15.59	16.66	17.67	18.63	19.54	20.41	21.24	22.82	24.29	26.35
30.0	13.78	15.91	17.79	19.48	21.04	22.50	23.86	25.15	26.38	27.55	28.68	30.81	32.80	35.57

From: USDA Soil Conservation Service. 1975. Procedure for computing sheet and rill erosion on project areas. Tech. Release No. 51 (rev.).

Type I effect: proportion of protected ground on road segment. The value for the Type I factor is determined from Figure 4, and from columns 4 and 5 on the field data sheet (Figure 1).

Type II effect: canopy cover (not in direct contact with soil surface). This factor is determined from Figure 5, and columns 11 and 12 on the field data sheet (Figure 1).

Type III effect: percent root network. This factor assesses the residual effects of land use by estimating the area of the road still containing roots, organic matter, and good soil structure, compared to the undisturbed forest floor. Column 13 on the field data sheet and Figure 6 are used to estimate the Type III effect.

These 3 subfactors are evaluated in the following equation to obtain VM, the vegetation-management factor:

$$VM = (\text{Type I}) \times [1 - (\text{Type II}) \times (\%\ \text{Bare Ground})] \times (\text{Type III}) \quad \text{(Eq. 2)}$$

Sedimentation

Water quality is impacted by erosion only if eroded soil reaches a functional channel. A number of factors influence this process of sedimentation, including the source and amount of sediment, proximity of the source to the receiving channel, texture of eroded material, microrelief, and watershed topography.

In order to estimate the amount of eroded soil reaching the channel system, the width of buffer strip between the road and channel is compared to the width of buffer needed to trap all sediment. This required width of filter strip was experimentally found to be 50 feet plus 4 times the perpendicular slope gradient between the road and channel (Trimble and Sartz, 1957). In the field, the slope gradient and distance between the base of a sampled road segment and the nearest functional channel (if any) are measured. The width of buffer strip required to trap sediment eroding from the road is then calculated as:

$$WBS = 50 + [4 \times (\%\ \text{slope between road \& channel})] \quad \text{(Eq. 3)}$$

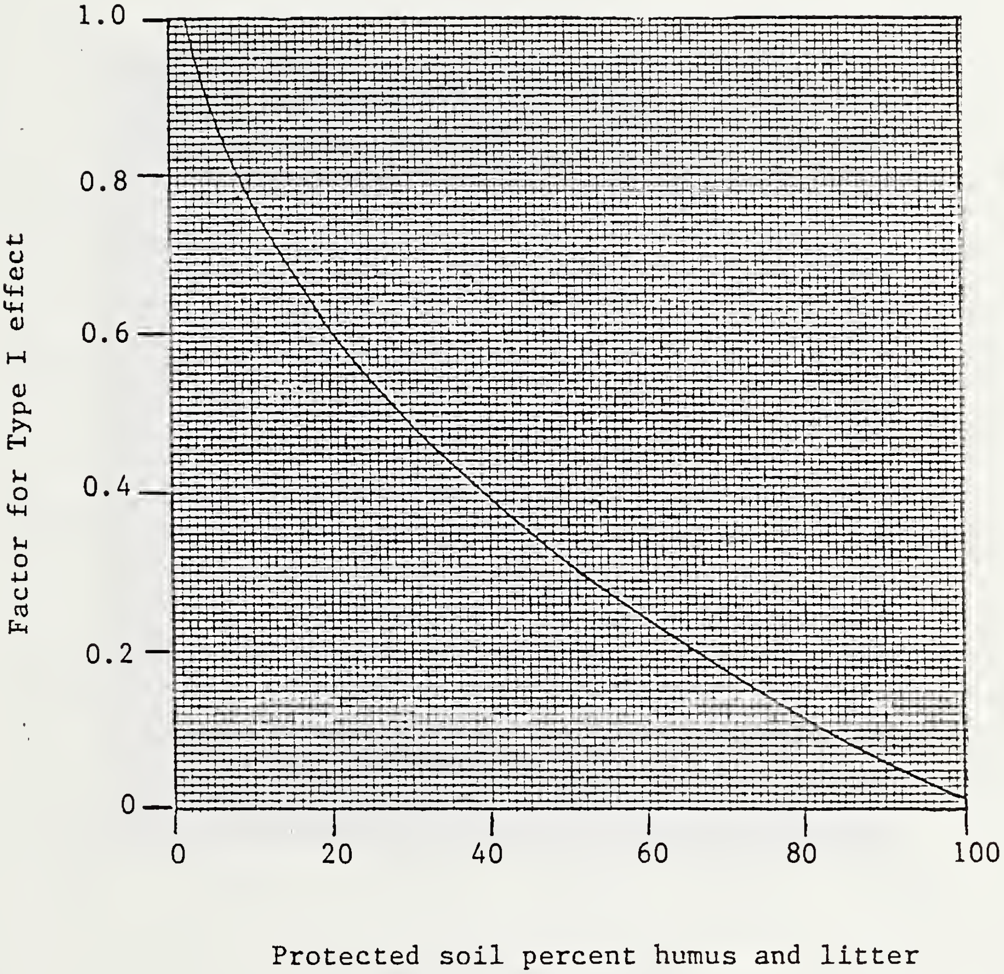
This required width is compared to the actual buffer strip. The Sediment Delivery Ratio is calculated in order to determine the proportion of eroded material reaching the stream as sediment:

$$SDR = 1 - \left[\frac{\text{Distance between road and channel}}{WBS}\right] \quad \text{(Eq. 4)}$$

This ratio, multiplied by A, the annual average erosion rate on the road segment (Equation 1), gives the amount of sediment in tons per acre per year transported to the channel:

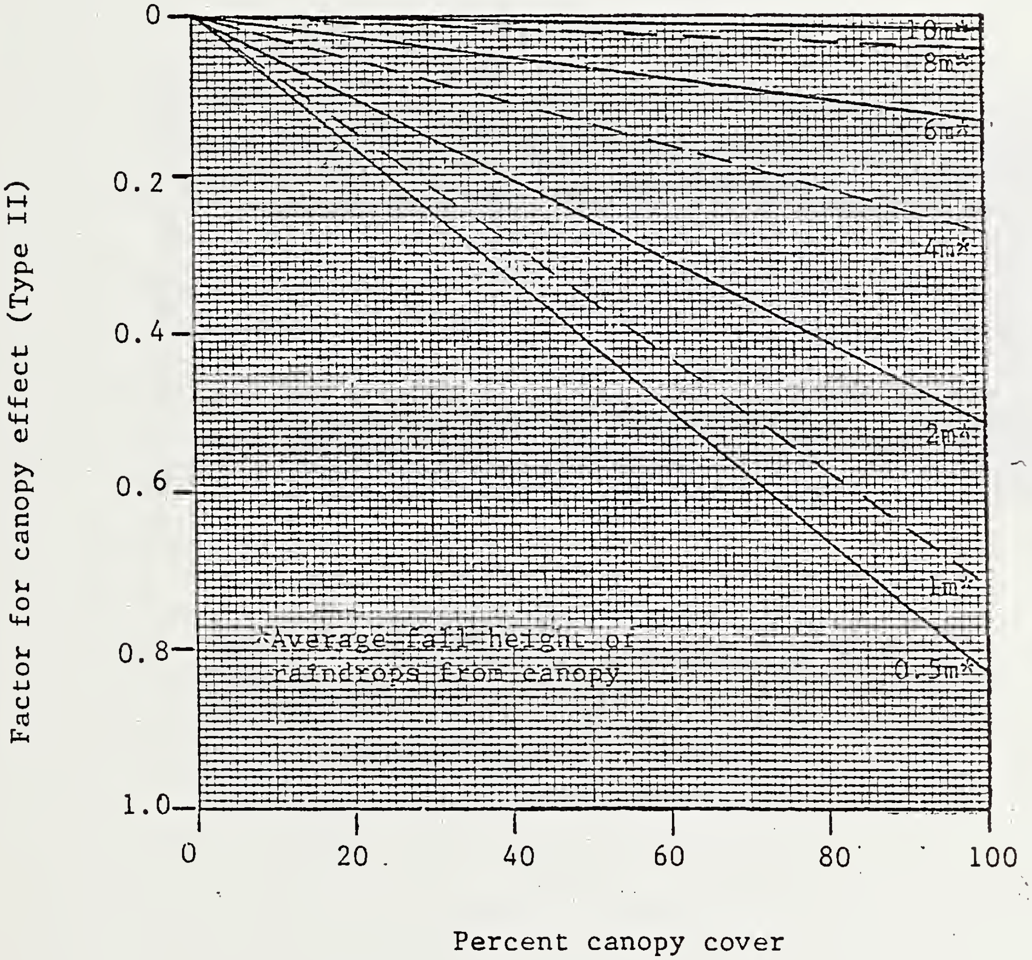
$$\text{Sedimentation Rate} = SDR \times A \quad \text{(Eq. 5)}$$

Figure 4. Type I: The effect of cover in direct contact with the soil



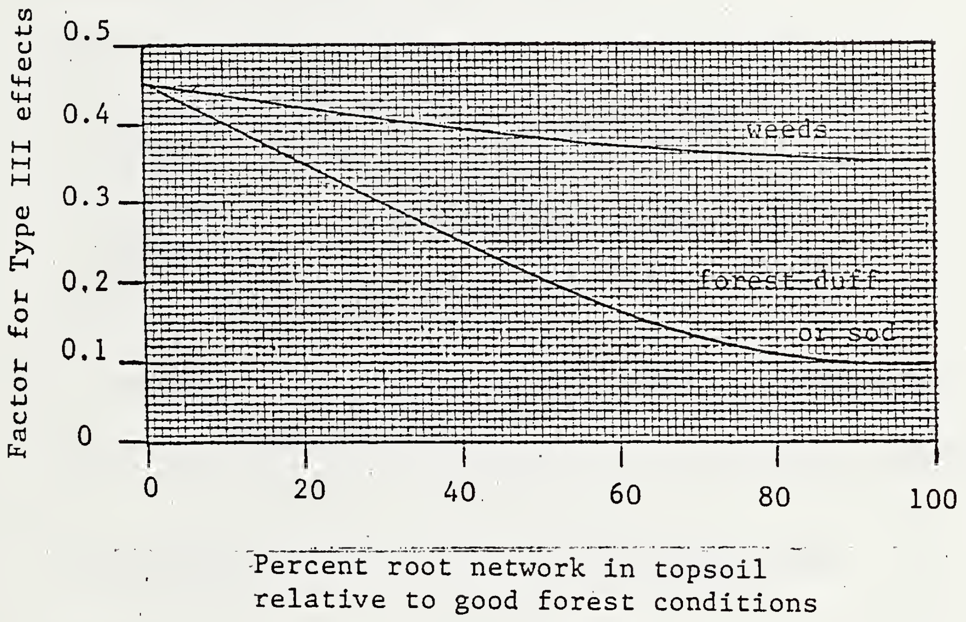
From: Wischmeier, W. H. 1975. Estimating the soil loss equation's cover and management factor for undisturbed areas. In: Present and Prospective Technology for Predicting Sediment Yield and Sources, USDA Ag. Res. Serv. ARS-S-40, 285pp.

Figure 5. Type II: The effect of the canopy cover



From: Wischmeier, W. H. 1975. Estimating the soil loss equation's cover and management factor for undisturbed areas. In: Present and Prospective Technology for Predicting Sediment Yield and Sources, USDA Ag. Res. Serv. ARS-S-40, 285pp.

Figure 6. Type III: The effect of root network



From: Wischmeier, W. H. 1975. Estimating the soil loss equation's cover and management factor for undisturbed areas. In: Present and Prospective Technology for Predicting Sediment Yield and Sources, USDA Ag. Res. Serv. ARS-S-40. 285pp.

Data Analysis Sheet

The computations discussed above may be done using a data analysis sheet, an example of which is provided in Figure 7. Sample calculations are illustrated in Figure 8, using data from a sample field data sheet (Figure 9). The step-by-step procedure used to generate the figures on the analysis sheet (Figure 8) is discussed below.

Analysis Sheet Column No.	Procedure
1	Transfer from column 3 on field data sheet (Figure 9)
2	Calculate from columns 4 and 5 on field data sheet: $\%\text{ Bare Ground (col. 2)} = \frac{\text{(col. 4)}}{\text{(col. 4 + col. 5)}} \times 100$
3	% Protected Ground = 100 - (col. 2)
4	Obtained from col. 3 and Figure 4 (see text)
5	Obtained from col. 13 on field data sheet, and Figure 6 (see text)
6	Use cols. 11 and 12 on field data sheet, and Figure 5.
7	Compute using Eq. 2 (see text) (col. 7) = (col. 4) x (col. 5) x [1 - (col. 6) x (col. 2)] Note: Express % Bare Ground (col. 2) as decimal fraction in equation
8	Obtained from cols. 6 and 7 on field data sheet and Table 1
9	From Figure 2
10	Obtained from published soil survey, or soil scientist.
11	Compute using Eq. 1: (col. 11) = (col. 7) x (col. 8) x (col. 9) x (col. 10)
12, 13	Transfer from columns 9 and 10, respectively, on field data sheet.
14	Compute from Equation 3: (col. 14) = 50 + [4 x (col. 12)]

EROSION & SEDIMENT PRODUCTION

WS ________ Site ________ R= __________ K= __________

EROSION											SEDIMENT						
Sample No. (1)	% Bare Ground (2)	% Prot. Ground (3)	TI (4)	TIII (5)	TII (6)	VM (7)	SL (8)	R (9)	K (10)	Erosion T/ac/yr (11)	To Stream % S (12)	To Stream L (ft) (13)	Width of Buffer Strip(WBS) (14)	Sed.Del. Ratio (13/14) (15)	Sed. Rate T/ac/yr (16)	Slope Class (17)	Road Type (18)

SUMMARY

Slope Class	Erosion n	Erosion $\bar{x}$	Erosion SD	Sediment n	Sediment $\bar{x}$	Sediment S
0-5 1						
6-10 2						
11-20 3						
21-30 4						
30 5						

Road Type	Erosion n	Erosion $\bar{x}$	Erosion SD	Sediment n	Sediment $\bar{x}$	Sediment
ST						
SR						
LR						
L						

Average for site

	Erosion	Sediment
n		
x		
SD		

Figure 7. Data analysis sheet

EROSION & SEDIMENT PRODUCTION

WS 20 Site 52 R= 80 K= 0.43

Sample No. (1)	% Bare Ground (2)	% Prot. Ground (3)	TI (4)	TIII (5)	TII (6)	VM (7)	SL (8)	R (9)	K (10)	Erosion T/ac/yr (11)	To Stream % S (12)	To Stream L (ft) (13)	Width of Buffer Strip (WBS) (14)	Sed. Del. Ratio (13/14) (15)	Sed. Rate T/ac/yr (16)	Slope Class (17)	Road Type (18)
	EROSION										SEDIMENT						
1	17	83	.10	.10	.66	.009	4.15	80	.43	1.29	—					4	ST
2	13	87	.08	.11	.05	.009	1.39			0.43	—					3	SR
3	20	80	.11	.10	.16	.011	.38			0.14	—					1	ST
4	83	17	.65	.45	.06	.278	.48			4.59	7	50	78	0.36	1.65	2	SR
5	7	93	.04	.10	.36	.004	1.15			0.16	4	40	66	0.39	.06	2	ST
[illegible]	12	88	.07	.30	.04	.021	2.51			1.86	15	0	110	1.0	1.86	3	SR
[illegible]	7	93	.04	.20	.07	.008	1.06			0.29	—					2	SR
[illegible]	82	18	.63	.45	0	.284	.76			7.42	—					1	L
[illegible]	88	12	.73	.45	.12	.294	.29			2.93	20	180	130	0	0	1	LR
[illegible]	11	89	.06	.45	.09	.027	.32			0.30	—					1	LR

SUMMARY

Slope Class	Erosion n	Erosion $\bar{x}$	Erosion SD	Sediment n	Sediment $\bar{x}$	Sediment S[illegible]
0-5 1	4	2.7	3.40		—	
6-10 2	3	1.7	2.52	2	0.9	1.[illegible]
11-20 3	2	1.2	1.01	1	1.9	—
21-30 4	1	1.3	—		—	
>30 5						

Road Type	Erosion n	Erosion $\bar{x}$	Erosion SD	Sediment n	Sediment $\bar{x}$	Sediment [illegible]
ST	3	0.5	0.66	1	.06	-
SR	4	1.8	2.00	2	1.8	0.[illegible]
LR	2	1.6	1.86		—	
L	1	7.4	-		—	

Average for site

	Erosion	Sediment
n	10	3
$\bar{x}$	1.9	1.2
SD	2.42	0.98

Figure 8. Example of erosion and sediment calculations

Watershed No. ______ Site No. ______ Ownership private Road Layout logger Date ___ 30

Road Type	# Paces btwn Samples	Sample No.	No. Paces w/ Bare Ground	No. Paces w/ Protected Grnd	Sample: % Slope	Sample: Length (ft)	Sample: Width (ft)	Sample to Channel: % Slope	Sample to Channel: Length (ft)	% Canopy Cover	Eff. Canopy Ht. (M)	% Root Network	Road Type	# Paces btwn Samples	Sample No.	No. Paces w/ Bare Ground	No. Paces w/ Protected Grnd	Sample: % Slope	Sample: Length (ft)	Sample: Width (ft)	Sample to Channel: % Slope	Sample to Channel: Length (ft)	% Canopy Cover	Eff. Canopy Ht (in)	% Root Network
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)													
ST	–	1	2	10	25	50	6	–	–	80	.5	90													
SR	100	2	7	1	15	30	8	–	–	60	7	80													
ST	100	3	3	12	5	50	8	–	–	60	4	95													
SR	100	4	10	2	6	50	10	7	56	30	5	0													
ST	100	5	1	14	10	70	6	4	40	95	3	100													
SR	100	6	4	30	15	100	10	15	0	50	7	30													
SR	100	7	1	13	10	60	8	–	–	80	7	50													
L	–	8	36	8	5	200	150	–	–	0	0	0													
LR	100	9	22	3	3	100	10	20	180	90	6	0													
LR	100	10	4	34	3	150	10	–	–	70	6	0													

Figure 9. Example of field data sheet

15	Compute using Equation 4: $$(\text{col. } 15) = 1 - \frac{(\text{col. } 13)}{(\text{col. } 14)}$$
16	Compute from Equation 5: $$(\text{col. } 16) = (\text{col. } 11) \times (\text{col. } 15)$$
17	Using percent slope from col. 6 on field data sheet, enter appropriate slope class code:

Code	Class
1	0-5%
2	6-10%
3	11-20%
4	21-30%
5	>30%

18	From col. 1 on field data sheet.

RESULTS

During the Fall of 1980, 45 logging sites were evaluated for erosion and sedimentation. These 45 sites occurred on 15 of the 17 watersheds[1/] in the study: the three watersheds without sample sites are highly agricultural areas with little forestry activity (Figure 10). A total of 24.1 miles of logging roads was walked during the survey, with 20.2 miles of this road distance classified as skid road, 3.0 miles as log road, and 0.9 mile as skid trail. Table 2 lists the road lengths in feet for each watershed. Acreage in roads is compared to the total acreage cut in Table 3. Both Tables 2 and 3 indicate a low proportion of skid trails compared to skid roads.

The soil types occurring on each site are listed in Table 4. Included in the table are the soil erodibility values (K), and the soil-loss tolerance factors (T), which are defined to be the maximum rates of soil erosion that can be tolerated without reducing crop production or environmental quality (Soil Conservation Service, 1979). A T value of 3.0 tons/acre/year will be used as a standard of comparison for the erosion rates encountered in the field survey. It should be noted that a normal soil loss rate for undisturbed eastern hardwood forest is 0.1 ton/acre/year or less (Patric, 1978).

Erosion

An average annual erosion rate for the transportation system and landings on each of the 45 logging sites was calculated as the mean of the erosion rates for all sample points measured on that site. These values, together

1/ The eighteenth watershed, Harvey's Lake, was added to the study after yield work was completed in Fall 1980. Harvey's Lake Watershed was surveyed in June 1981, and is analyzed in Appendix A.

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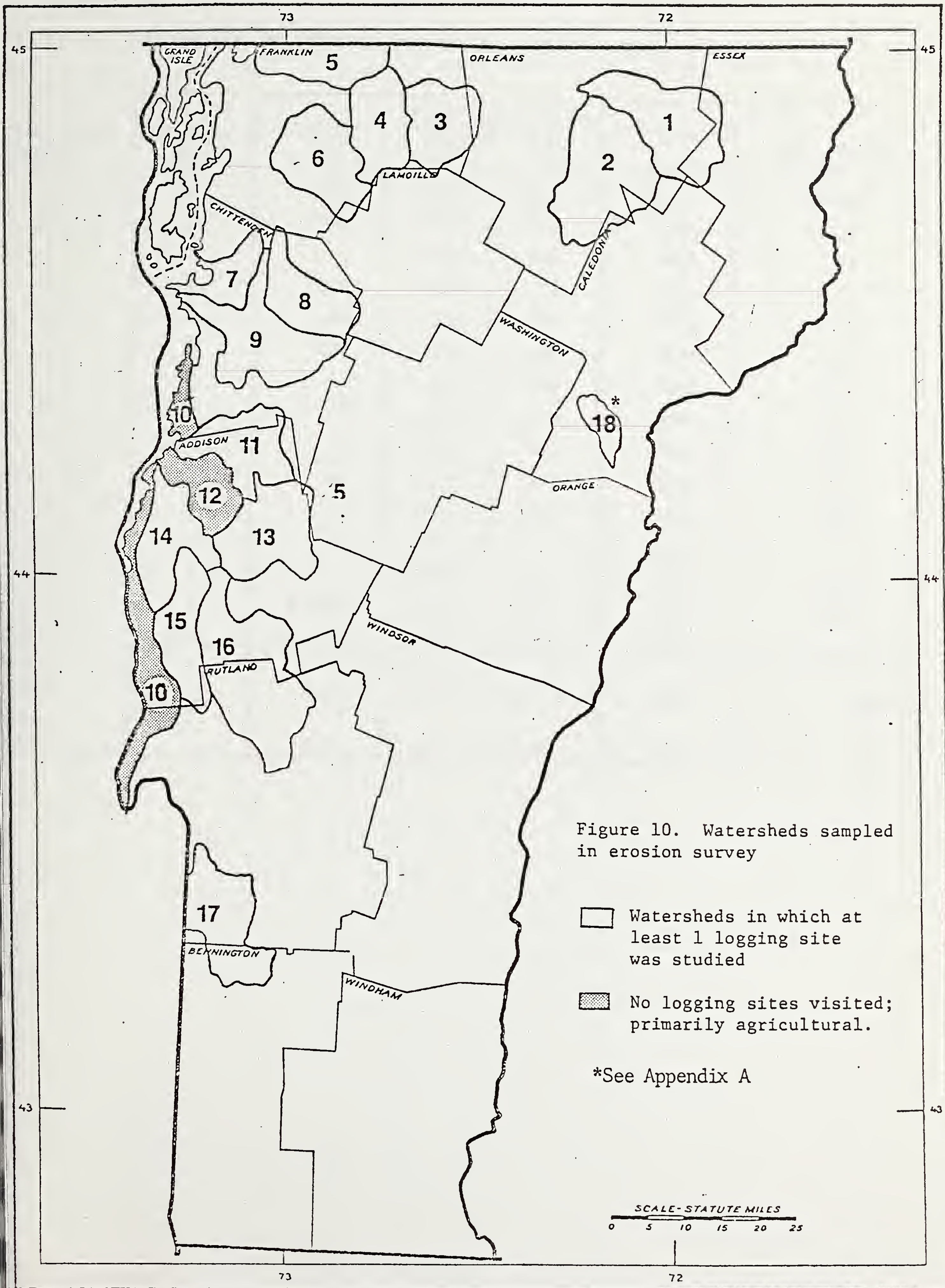

Figure 10. Watersheds sampled in erosion survey

Table 2. Road lengths and landing acreages in erosion survey

Watershed Number	No. of Sites	Road Length (feet) Skid Trail	Skid Road	Log Road	Total	Area (acres) Landing
1	4	1092	14500	3524	19116	1.80
2	8	1324	16876	904	19104	0.69
3	2	--	5188	436	5624	1.15
4	2	268	4804	56	5128	0.04
5	1	396	1736	400	2532	0.94
6	2	708	6192	1380	8280	0.06
7	3	92	3116	1648	4856	0.23
8	2	--	3388	252	3640	0.51
9	4	76	7180	984	8240	0.26
11	1	44	3120	960	4124	0.12
13	2	--	5524	2048	7572	0.51
14	1	--	2236	--	2236	--
15	2	--	6896	596	7492	0.30
16	4	308	6740	996	8044	0.26
17	7	428	18956	1388	20772	0.47
TOTAL (feet)		4736	106452	15572	126760	7.34 acres
TOTAL (miles)		0.9	20.2	3.0	24.0	

Table 3. Acreage in road system, and area in road system as a percent of total acres harvested.

Watershed No.	Units	Skid Trail	Skid Road	Log Road	Landing	All Roads & Landings	Total Area Cut (acres)
1	Acres	.22	3.46	.96	1.80	6.44	385
	%	.06	.90	.25	.47	1.67	
2	Acres	.28	4.37	.18	.69	5.52	510
	%	.05	.86	.04	.14	1.08	
3	Acres	--	1.41	.12	1.15	2.69	130
	%	--	1.09	.10	.88	2.07	
4	Acres	.04	.87	.02	.04	.96	105
	%	.04	.82	.01	.04	.91	
5	Acres	.06	.28	.07	.94	1.35	30
	%	.20	.93	.23	3.13	4.50	
6	Acres	.11	1.39	.29	.06	1.85	200
	%	.06	.70	.14	.03	.93	
7	Acres	.01	.53	.23	.23	1.00	50
	%	.03	1.06	.46	.46	2.01	
8	Acres	--	.74	--	.51	1.25	120
	%	--	.62	--	.43	1.04	
9	Acres	.01	1.08	.18	.26	1.53	140
	%	.01	.77	.13	.19	1.09	
11	Acres	.01	.50	.15	.12	.78	25
	%	.02	2.00	.62	.48	3.12	
13	Acres	--	1.33	.52	.51	2.36	120
	%	--	1.11	.43	.43	1.96	
14	Acres	--	.36	--	--	.36	10
	%	--	3.59	--	--	3.59	
15	Acres	--	1.37	.11	.30	1.78	90
	%	--	1.52	.12	.33	1.98	
16	Acres	.06	1.49	.23	.26	2.04	130
	%	.04	1.15	.18	.20	1.57	
17	Acres	.05	2.91	.64	.47	4.07	350
	%	.01	.83	.18	.13	1.16	

Table 4. Soil types, erodibility factors (K), soil tolerance values (T) by logging site

Watershed Number	Site No.	Soil Type(s)	K Factor	T Value
1	1,2	Glover	0.43	2
		Cabot	0.28	3-2
	3	Glover	0.43	2
		Cabot	0.28	3-2
		Calais	0.28	3-2
	11	Glover	0.43	2
		Cabot	0.28	3-2
		Buckland	0.28	3
2	4	Glover	0.43	2
		Buckland	0.28	3
	5	Glover	0.43	2
		Cabot	0.28	3-2
	6	Glover	0.43	2
		Cabot	0.28	3-2
		Buckland	0.28	3
	7	Glover	0.43	2
		Calais	0.28	3-2
	8	Glover	0.43	2
	9,10,12	Glover	0.43	2
		Cabot	0.28	3-2
3	13	Peru	0.43	3
	19	Peru	0.43	3
		Stowe	0.43	3
4	14	Missisquoi	0.17	2
		Woodstock	0.43	2
	18	Woodstock	0.43	2
5	16	Woodstock	0.43	2
6	15,17	Peru	0.43	3
		Woodstock	0.43	2
7	37	Adams	0.17	-
		Windsor	0.17	5
		Hinesburg	0.17	-
	38	Lyman	0.43	-
		Marlow	0.43	-
	39	Adams	0.17	-
		Hinesburg	0.17	-
		Stockbridge	0.28	-
		Nellis	0.28	-
8	41,42	Lyman	0.43	-
		Marlow	0.43	-
		Cabot	0.28	3-2
9	40,45	Lyman	0.43	-
		Marlow	0.43	-
	43,44	Adams	0.17	-
		Windsor	0.17	5
11	36	Lyman	0.43	-
		Marlow	0.43	-
13	26	Berkshire	0.43	-
		Marlow	0.43	-
	35	Berkshire	0.43	-
		Marlow	0.43	-
		Lyman	0.43	-
14	34	Vergennes	0.43	-
15	24,25	Vergennes	0.43	-
16	20	Berkshire	0.43	-
		Cabot	0.28	3-2
	21,22	Berkshire	0.43	-
	23	Peru	0.43	3
17	27,30	Macomber	0.28	3
		Taconic	0.24	2
	28,29	Macomber	0.28	3
		Taconic	0.24	2
		Dutchess	0.28	3
	31,32	Dutchess	0.28	3
	33	Dutchess	0.28	3
		Macomber	0.28	3

with the standard deviations of the means, number of sample points, and the range of erosion rates encountered at each site are presented in Table 5. Nineteen of the 45 sites (42%) had an average erosion rate on the road system in excess of 3.0 tons/acre/year, with a range of 0.2 to 34.6 tons/acre/year.

Table 6 is a summary of the erosion data by watershed, with the average erosion rate calculated as the mean of all sample points for all sites on each of the 15 sampled watersheds. The standard deviations and range of values are also presented. Ten of the 15 watersheds (67%) had mean erosion rates in excess of 3.0 tons/acre/year on the roads and landings, with a range of 0.2 to 15.2 tons/acre/year (Figure 11).

Table 6. Average annual erosion rates on roads and landings (by watersheds)

Watershed Number	No. of Sample Pts	A (t/ac/y)	Std. Dev.	Low (t/ac/yr)	High (t/ac/yr)
1	63	6.5	13.52	0	78.8
2	63	10.6	23.23	0	129.3
3	21	15.2	19.80	0.5	69.1
4	21	2.3	3.14	0	9.9
5	16	0.6	1.11	0	4.5
6	31	5.9	13.45	0	65.8
7	21	1.0	2.16	0	10.1
8	18	3.9	4.52	0	17.1
9	37	9.5	24.79	0	121.4
11	16	8.0	7.91	0.3	26.4
13	23	8.6	11.72	0.2	34.2
14	9	0.2	0.24	0.1	0.5
15	20	6.0	7.70	0.1	32.5
16	31	2.9	3.60	0.1	12.1
17	85	7.8	17.06	0	93.0

Table 5. Average annual erosion rates on roads and landings (by logging sites)

Watershed Number	Site No.	A (t/ac/y)	Std Dev.	Low (t/ac/yr)	High (t/ac/yr)	No. of Sample Pts	Physiographic Region
1	1	13.5	14.54	0.2	39.3	8	Vermont Piedmont
	2	10.4	18.38	0	78.8	25	" "
	3	1.5	3.03	0.1	13.1	18	" "
	11	1.3	1.91	0.1	6.9	12	" "
2	4	0.4	0.24	0.2	0.7	4	" "
	5	3.1	7.18	0	26.1	13	" "
	6	1.2	1.59	0	3.3	6	" "
	7	22.7	22.54	2.2	75.5	11	" "
	8	34.6	47.05	0	129.3	9	" "
	9	5.6	6.39	0.1	14.7	6	" "
	10	2.4	3.35	0.3	10.2	8	" "
	12	0.5	0.69	0	1.8	6	" "
3	13	1.2	1.25	0.2	3.9	7	Green Mountains
	19	22.1	21.10	0.5	69.1	14	" "
4	14	1.1	2.20	0	7.1	10	Champlain Lowlands
	18	3.3	3.58	0	9.9	11	Green Mountains
5	16	0.6	1.11	0	4.5	16	Champlain Lowlands
6	15	0.4	0.75	0	2.7	12	Champlain Lowlands
	17	9.3	16.41	0	65.8	19	Green Mountains
7	37	0.5	0.65	0	1.8	11	Champlain Lowlands
	38	0.8	0.42	0.3	1.4	5	" "
	39	2.3	4.41	0	10.1	5	" "
8	41	5.3	4.62	0	17.1	13	Green Mountains
	42	0.4	0.5	0	1.2	5	Champlain Lowlands
9	40	0.7	0.86	0.1	2.4	7	Champlain Lowlands
	43	2.1	2.36	0.1	5.9	11	" "
	44	1.2	1.98	0	5.9	9	" "
	45	31.3	41.50	1.1	121.4	10	Green Mountains
11	36	8.0	7.91	0.3	26.4	16	Champlain Lowlands
13	26	10.7	12.76	1.2	48.3	13	Green Mountains
	35	5.9	10.20	0.2	34.2	10	" "
14	34	0.2	0.24	0.1	0.5	9	Champlain Lowlands
15	24	4.1	1.99	1.3	6.4	6	" "
	25	6.8	9.10	0.1	32.5	14	" "
16	20	0.4	0.28	0.1	0.8	4	Green Mountains
	21	3.1	2.79	0.1	8.7	8	" "
	22	2.1	4.48	0.2	2.4	6	" "
	23	4.6	4.48	0.1	12.1	13	" "
17	27	1.1	1.98	0	7.9	12	Taconic Mountains
	28	1.1	1.70	0.2	5.2	8	" "
	29	0.3	0.36	0	0.7	3	" "
	30	2.0	4.37	0	16.8	16	" "
	31	26.2	26.39	1.2	93.0	22	" "
	32	2.5	1.44	0.3	5.7	16	" "
	33	2.4	4.01	0	12.0	8	" "

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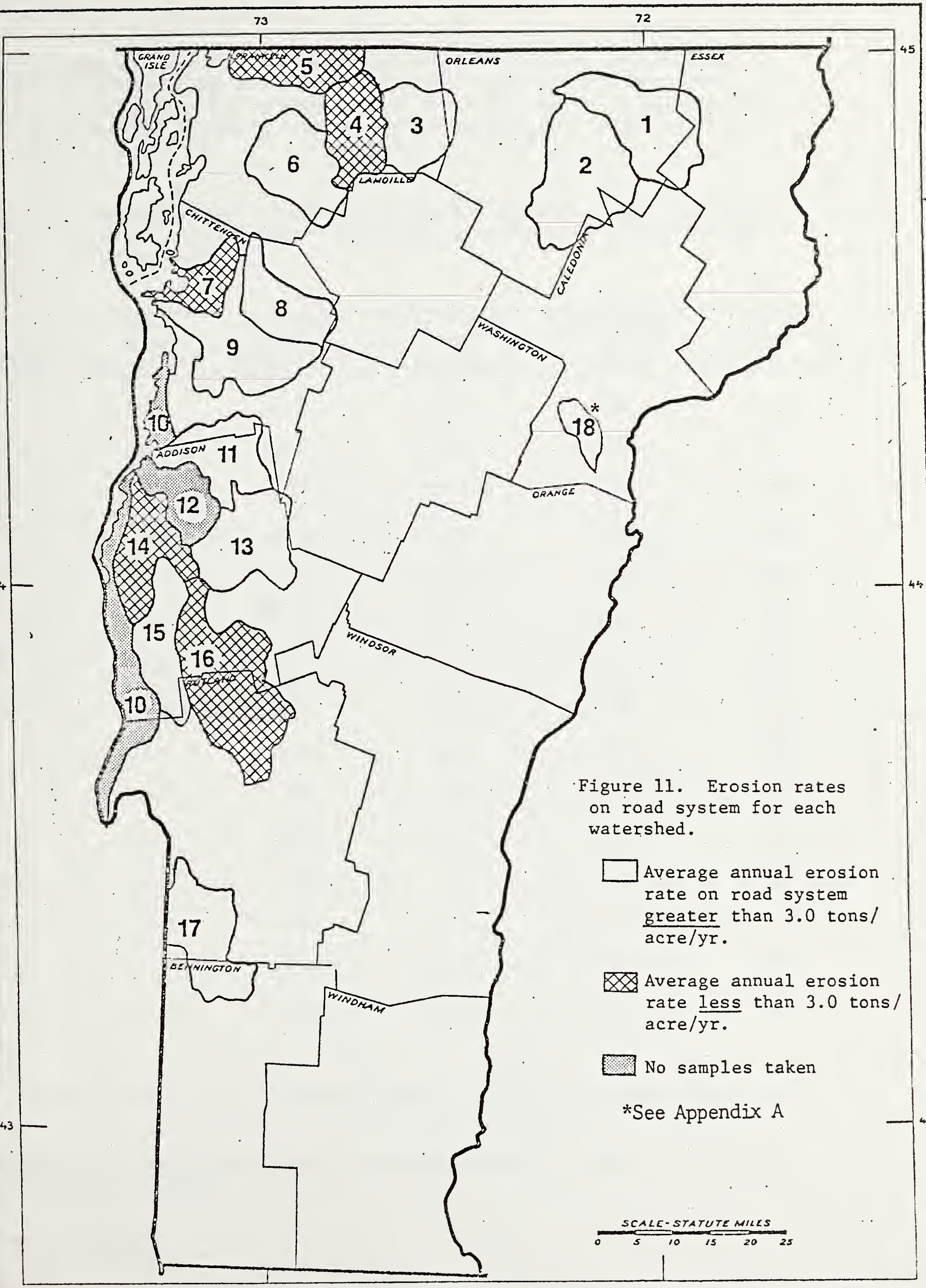

Figure 11. Erosion rates on road system for each watershed.

Overall erosion rates for the harvested areas as a whole, not just the roads and landings, are presented in Table 7. The figures range from 0.11 to 0.41 ton/acre/year, showing that on an area basis, erosion rates far below the SCS tolerable loss rate of 3 tons/acre/year are occurring on logging sites.

Table 7. Volumes of soil eroded from roads and harvested areas, and overall annual erosion rates from entire harvested areas (derived from Tables 6 and 3).

Watershed Number	Road Erosion (tons/year)	Non-Road* Erosion (tons/year)	Total Erosion from Harvest Area (tons/year)	Total Acres in Harvest Areas	Overall Erosion Rate (tons/acre/year)
1	41.9	37.9	79.8	385	0.21
2	58.5	50.5	109	510	0.21
3	40.9	12.7	53.6	130	0.41
4	2.2	10.4	12.6	105	0.12
5	0.8	2.9	3.7	30	0.12
6	10.9	19.8	30.7	200	0.15
7	1.0	4.9	5.9	50	0.12
8	4.9	11.9	16.8	120	0.14
9	14.5	13.9	28.4	140	0.20
11	6.2	2.4	8.6	25	0.34
13	20.3	11.8	32.1	120	0.27
14	0.1	1.0	1.1	10	0.11
15	10.7	8.8	19.5	90	0.22
16	5.9	12.8	18.7	130	0.14
17	31.8	34.6	66.4	350	0.19

*Erosion rate on undisturbed area taken as 0.10 ton/acre/year (Patric 1978)

The annual average erosion rates for logging sites are summarized below by physiographic region:

Table 8. Average annual erosion rates on roads and landings by physiographic region

Physiographic Region	A (t/ac/y)	Std Dev.	(t/ac/yr) Low	High	No. of Sites
Vermont Piedmont	8.1	10.74	0.4	34.6	12
Green Mountains	8.3	9.33	0.4	31.3	12
Champlain Lowlands	2.1	2.49	0.2	8.0	14
Taconic Mountains	5.1	9.34	0.3	26.2	7

A striking difference exists between the three mountainous regions and the flatter Champlain Lowlands in terms of both average annual erosion rates and of the range of erosion rates. Sixteen of the 31 sites (52%) in the mountainous regions had erosion rates greater than 3.0 tons/acre/year, whereas only 3 of the 14 Lowlands sites (21%) exceeded this rate. Figure 12 shows the approximate location of the 45 sites in relation to the physiographic regions, and indicates which sites have an annual average erosion greater than 3.0 tons/acre/year.

The strong relationship between topography and erosion is further illustrated when the sample point data are stratified by slope class. Figure 13 presents this analysis graphically: the histogram clearly shows that higher erosion rates occur on steep slopes.

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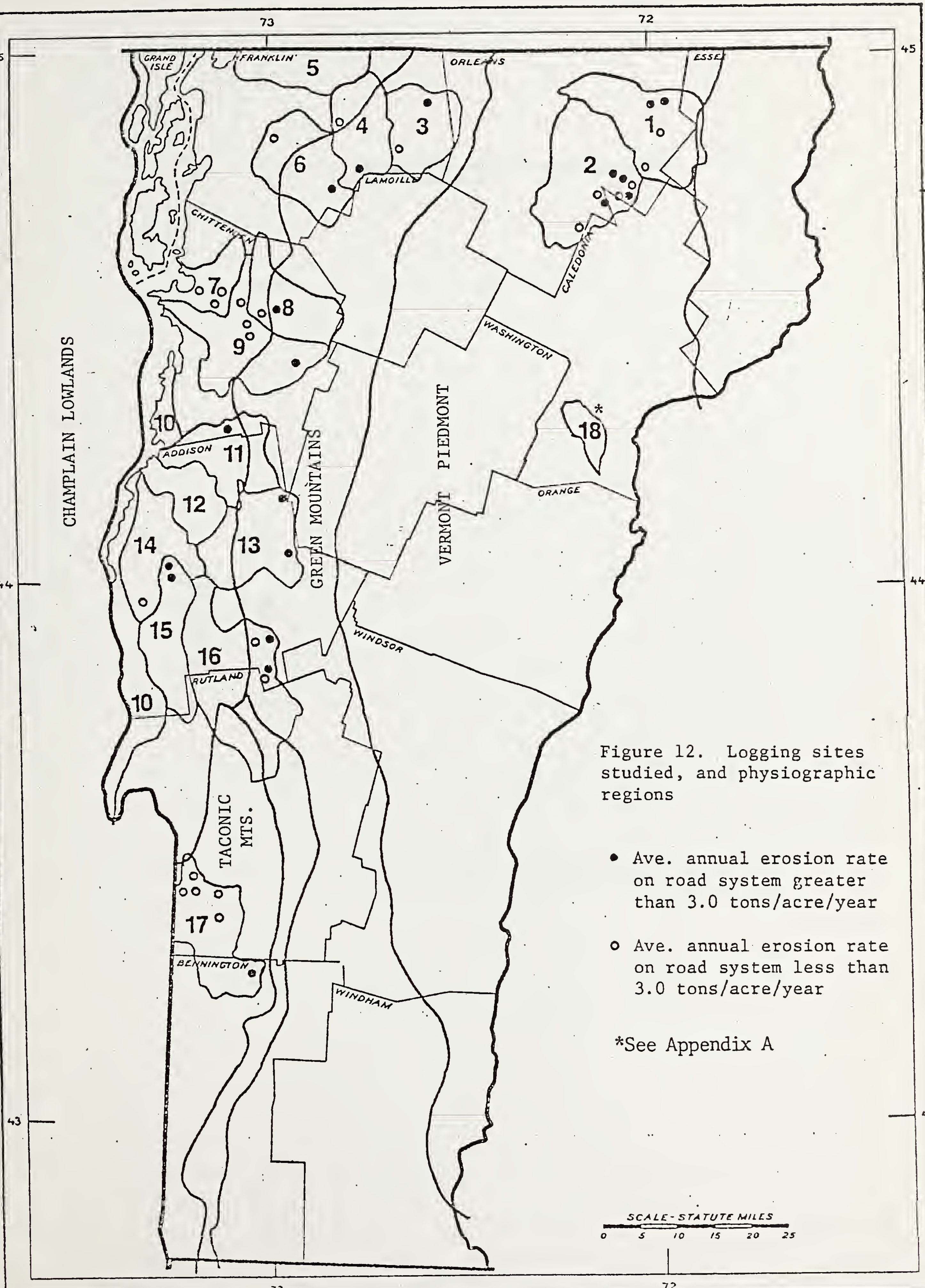
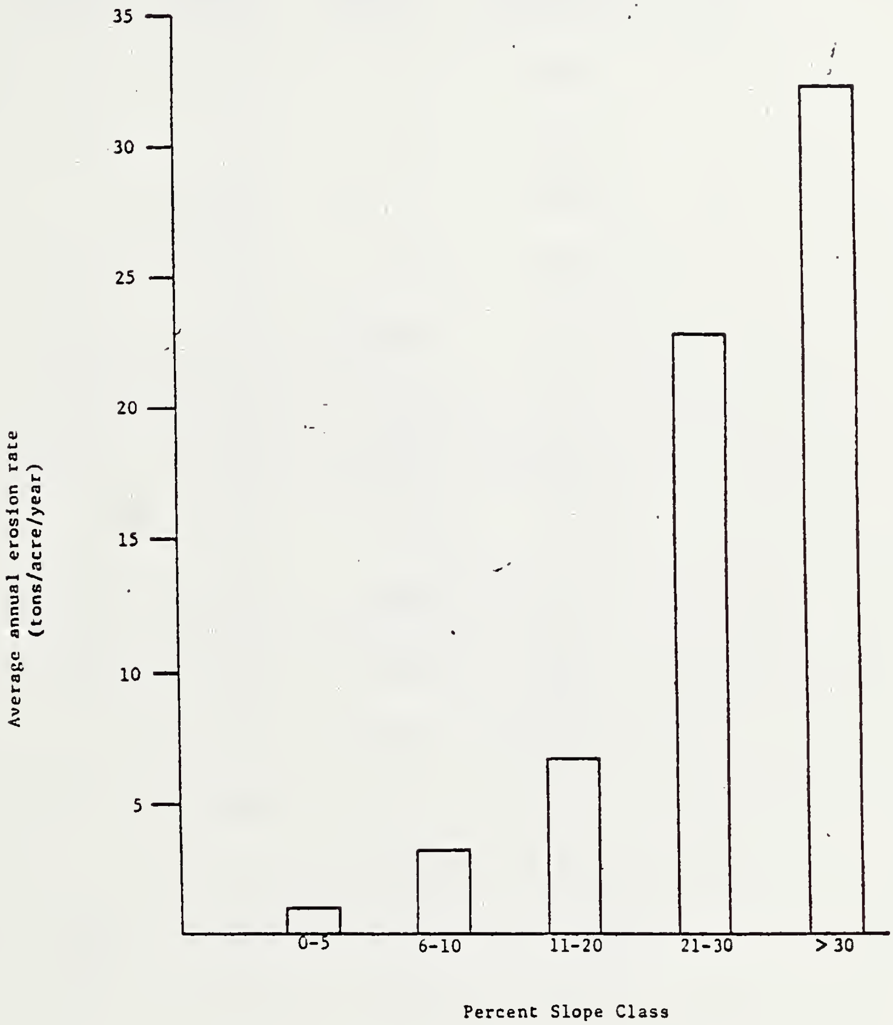


Figure 12. Logging sites studied, and physiographic regions

- ● Ave. annual erosion rate on road system greater than 3.0 tons/acre/year
- ○ Ave. annual erosion rate on road system less than 3.0 tons/acre/year

*See Appendix A

Figure 13. Average annual erosion rates from road system, grouped by slope class



The average annual erosion rates are stratified by watershed and road type in Table 9. Included are the overall mean erosion rates for each category of road, and for landings.

Table 9. Annual average erosion rates by road type

	A (tons/acre/year)			
Watershed No.	Skid Trail	Skid Road	Log Road	Landing
1	6.7	4.9	7.9	10.7
2	3.5	9.7	1.9	9.7
3	--	13.0	10.1	6.5
4	0.3	3.2	1.8	0.4
5	0.1	0.6	0.6	1.0
6	0.1	6.4	0.2	0.1
7	0.1	0.4	5.5	0.5
8	--	2.6	---	4.5
9	1.3	11.1	3.8	2.3
11	0.3	8.7	8.4	6.3
13	---	9.2	10.9	3.3
14	---	0.2	---	---
15	---	4.7	14.8	6.7
16	0.2	2.6	3.6	1.5
17	0.4	5.7	1.8	6.4
Mean	1.3	5.5	5.5	4.3
Std. Dev.	2.17	4.06	4.56	3.51
No. of Watersheds	10	15	13	14

Table 10 below indicates how many sites in each category had erosion rates greater than 3.0 tons/acre/year:

Table 10. Average annual erosion rates in excess of tolerable soil loss (T = 3 ton/ac/yr) by road type.

Road Type	No. of Sites	No. sites in excess of T	Percent
Skid Trail	28	2	7
Skid Road	45	20	44
Log Road	33	14	42
Landing	32	13	41

Both Tables 9 and 10 indicate that skid trails erode at a very low rate, whereas skid roads, log roads, and landings all show erosion occurring at rates greater than the tolerable soil loss rate. This result is most likely due to the smaller amount of exposed mineral soil on skid trails compared to the other road types and landings.

From information provided by the county foresters, the sites were stratified according to the type of technical assistance employed by the landowner: (1) county forester, (2) private consultant or other professional forester, or (3) no assistance (logger's choice). This analysis is summarized below:

Table 11. Average annual erosion rates on roads and landings grouped by technical assistance.

Type of Assistance	A (t/ac/y)	Std. Dev.	No. of Sites	Lowest Rate	Highest Rate
County Forester	3.4	3.70	10	0.3	10.7
Consultant	6.2	7.98	9	0.5	26.2
Logger	7.0	9.95	25	0.2	34.6

It is apparent that sites with county forester assistance had lower erosion, in terms of both average annual rate of erosion and highest rate on a site.

Sedimentation

Thirty-one of the 45 logging sites (69%) showed some eroded soil reaching an active channel as sediment. When the site data are averaged by watershed, 13 of the 15 sampled watersheds had sedimentation occurring on them (Table 12). It should not be concluded that the remaining two watersheds have no sedimentation problem: only one site was sampled on each of those watersheds.

Table 12. Average annual sedimentation rates and total tons of sediment delivered by road system annually.

Watershed	Sed. Rate			Total Sediment		
Number	t/ac/yr	Low	High	tons/year	Low	High
1	1.8	0.1	4.9	5.2	0.03	15.3
2	2.8	0.02	14.5	3.2	0.01	18.5
3	4.4	0.3	8.5	9.6	0.1	19.1
4	0.9	0.7	1.1	0.5	0.2	0.7
6	4.6	--	--	5.9	--	--
7	0.2	0.1	0.3	0.1	0.06	0.08
8	0.9	0.2	1.6	0.9	0.03	1.7
9	0.3	0.1	0.5	0.1	0.02	0.3
11	1.6	---	---	1.2	---	---
13	2.5	0.02	5.0	4.7	0.01	9.4
15	0.4	---	---	0.2	---	---
16	1.3	0.1	2.5	1.0	0.03	2.0
17	0.7	0.4	1.2	0.9	0.3	2.0

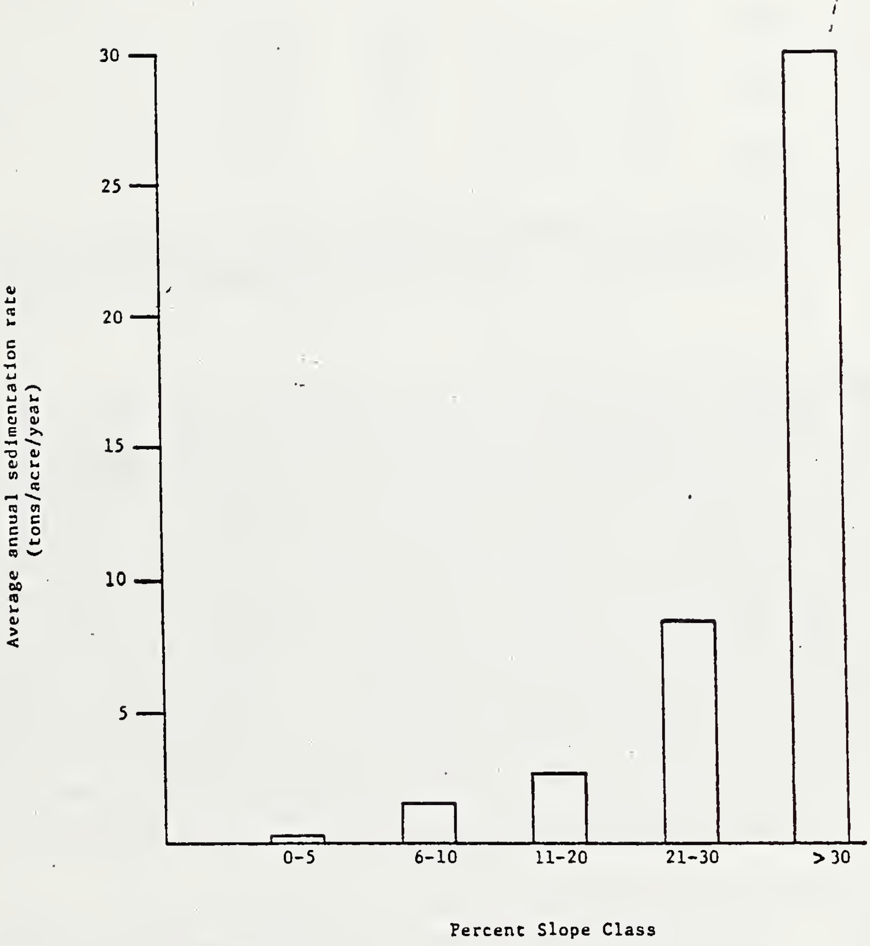
As was true for erosion rates, the relationship of topography to sedimentation is indicated by grouping the data by physiographic region:

Table 13. Average annual sedimentation rates and total sediment delivered by road system, grouped by physiographic region.

Physiographic Region	# Sites	Sed. Rate t/ac/yr	Sed. Rate Low	Sed. Rate High	Total Sediment tons	Total Sediment Low	Total Sediment High
Vermont Piedmont	10	2.5	.02	14.5	2.5	.01	18.5
Green Mountains	9	2.6	.02	8.5	4.3	.01	19.1
Taconic Mountains	3	0.7	0.4	1.2	0.9	0.3	2.0
Champlain Lowlands	9	0.5	0.1	1.6	0.2	.02	1.2

This dependence on slope is further illustrated when the data are grouped by slope class, as is done graphically in Figure 14.

Figure 14. Average annual sedimentation rate from road system, grouped by slope class



The sedimentation rates and total sediment yield from the road system are summarized by type of technical assistance in Table 14.

Table 14. Average annual sedimentation rates and sediment yield from road system, grouped by technical assistance.

Type of Assistance	# of Sites	Sed. Rate			Total Sediment		
		t/ac/yr	Low	High	tons	Low	High
County Forester	4	1.5	.06	5.0	2.4	.02	9.4
Consultant	7	1.1	.03	4.6	1.3	.03	5.9
Logger	20	2.1	.02	14.5	3.2	.01	19.1

As was the case for erosion rates, sites which had no technical assistance showed higher rates of sedimentation from roads and landings.

DISCUSSION

Research throughout the East indicates that undisturbed forests erode at a normal, or geologic rate of 0.05 to 0.10 ton/acre/year (Patric, 1976). Two interrelated characteristics of the forest environment, the high infiltration capacity of the soil and the protective nature of the forest floor, are responsible for the low rate of erosion. Forest soils are commonly capable of infiltrating water at rates of 50 or more inches per hour, whereas rainfall intensities greater than 2 inches per hour are rare in the East (Patric, 1978). With all rain entering the soil, overland flow is virtually non-existent in undisturbed forests, and thus the major agent of erosion, moving water, is likewise non-existent. The forest floor, composed of freshly-fallen and decomposing layers of litter, absorbs all of the kinetic energy of rain. Absorption of the erosive force of rain prevents detachment of soil particles that can plug and seal soil pores, which in turn can reduce infiltration capacity.

What then causes the accelerated erosion from logging operations? The simple act of cutting trees does not increase erosion rates. Rather it is the act of transporting the logs through the forest and off the site that creates erosion problems. Alteration of the soil's infiltration capacity and disturbance of the forest floor are the causes of accelerated erosion from roads and landings. Heavy equipment used in logging such as skidders, log loaders, and log trucks all compact the soil, which decreases the infiltration rate. Removal of the protective litter layers by bulldozers and skidded trees exposes bare mineral soil to the impact of rain. Conditions are thus created which can and do lead to overland flow and accelerated soil loss.

This study confirmed that high rates of erosion can occur on roads used for timber harvesting (see Table 6). It also illustrated that the slope of a road is overwhelmingly important in the erosion process. Even a

relatively gentle slope can show significant erosion if its length is excessive. In areas characterized by steep slopes, such as the Piedmont, Green Mountains, and Taconic Mountains regions, roads must be located with great care. Road gradients should be kept at the least below 20%, and preferably below 10%, which would not only minimize erosion, but would also be of economic benefit to the logger in terms of decreased equipment wear and repairs. If a steep gradient must be used, due to property line constraints or physical obstructions, the steep pitches should be kept as short as possible.

Table 11 indicates that the erosion rates on harvest jobs which had the assistance of a county forester are considerably below that of jobs with a private consultant's or no assistance. The county foresters interviewed during this study indicated that in addition to marking timber to be cut for a landowner, they usually also flag the location of the major roads. The lower erosion rates for such sites may be a reflection of better road location due to their assistance, compared to the unsupervised logger's choice of road location. No private consultants were interviewed, so it is not known whether they generally include road layout in their services.

An important point brought up by several county foresters was the need for close supervision of most loggers in order to insure adherence to the forester's recommended cuttings and road layout. Generally, the State's limit of two days assistance by the forester for each landowner per year prevents the forester from such close supervision. It is thus extremely important that the landowner be aware of the need to follow the forester's recommended silvicultural practices and road layout, and of the need for the landowner to exercise vigilance over the logger's actions.

Eroded soil from logging roads becomes a water quality problem if the soil reaches a functional stream channel. Sediment can adversely impact aquatic life such as trout by (1) reducing primary production of plants and food organisms, (2) increasing susceptibility of fish to disease, and (3) destroying spawning habitat. Accelerated sedimentation rates are also responsible for reducing reservoir storage and water carrying capacity of stream channels, and in raising the cost of water treatment (Lynch et al., 1977). Professional assistance by county foresters or private consultants resulted in less eroded soil reaching water channels from the roads used during logging operations. The lower erosion rates from sites with assistance may account for the lower sedimentation. Presumably, the decreased sediment yields may also be a result of foresters locating the roads a sufficient distance from streams to provide an adequate buffer strip. Such buffer strips should be minimally disturbed during logging, so that the forest floor can filter and trap any soil eroding from the road or landing.

Accelerated loss of soil from logging operations generally halts within two or three years after harvest, as a result of two natural processes. One is the revegetation of disturbed sites by herbaceous and grass species. In the humid East, this natural re-growth is usually fairly rapid, resulting in a generally complete protective cover two years after harvest. Secondly, a stony pavement can form that will effectively "armor" the soil against further erosion. This pavement forms when erosion has

removed the top layer of soil, leaving behind rocks and small stones that form a solid cover over the remaining soil. This process is illustrated by the occurrence of "pedestals", small pillars of soil capped by a stone. Most forest soils in Vermont are very stony and readily form such pavements, which accounts for the general lack of gullying on the sites studied. Use of the Soil Loss Equation on "armored" roads may show very little erosion occurring in the present, but will not measure the amount of soil that had to be washed away in order to form such a pavement.

Can anything be done to minimize soil loss from logging roads, besides waiting for a pavement to form or vegetation to grow? Yes, it is possible to keep erosion during harvesting down to the low rate characteristic of undisturbed forests by proper design, location, and maintenance of the road system (Aubertin and Patric, 1974). The means for doing so are well-known and have been widely publicized (VT Agency for Environmental Conservation, n.d.; Hartung and Kress, 1977). These methods are summarized below:

1) Plan the road system in advance of logging in order to have as few roads and skid trails as possible.

2) Keep road and trail gradients below 10%. If a steeper grade is unavoidable, keep the steep pitch as short as possible.

3) Locate roads parallel to and away from streams. Never operate equipment in the stream channel.

4) Provide good drainage on the roads with broad-based dips, variable grades, culverts, etc. Don't operate equipment on soft roads during the wet season.

5) Put the road to "sleep" after logging by outsloping, installing water bars, seeding, etc., in order to prevent erosion and protect the landowner's investment in the road.

That high erosion rates were found in the study areas indicates that measures to control erosion are not universally applied. The remedy is to inform and educate both loggers and landowners about the importance of preventing erosion and sedimentation from harvesting operations, and of the benefits that will accrue to them as a result of good road construction. For the logger, the cost of putting in a stable, non-eroding road system may be higher in the short term, with the added cost most likely passed on to the landowner in the form of lower stumpage prices. In the long term, however, a dry road with low grades will save the logger time and money in equipment wear and repair. A more intangible benefit to the logger of carrying out a logging job in a conscientious manner is the potential for increased access to more privately owned timber in the future. Landowners are frequently reluctant to sell stumpage because they believe that loggers "butcher" the site. A logger with a reputation for leaving a harvest site and roads in good and usable condition will find it easier to buy timber from such landowners.

The self-policing program conducted since mid-1979 by the Vermont Timber Truckers and Producers Association (VTTPA) has been useful in instilling a new attitude and higher level of responsibility among participating loggers.

Another program instituted under the state Water Quality Plan is the education of loggers, landowners, VTTPA committeemen and Water Resources Investigators in erosion control practices for forestry operations. Both of these programs are directed towards solving erosion problems voluntarily, and should be continued in order to reach more people.

Ultimately the landowner controls the quality of roads built on his property. Although a landowner's primary interest in selling timber may be the income generated, if he is aware of the other benefits gained from timber harvesting and road construction he will be motivated to insure that the logger harvests in a sound manner. A well-constructed road system can improve access to his property for recreation (hiking, hunting, birdwatching, etc.), for firewood removal, and for future commercial harvests. Creating openings in a closed forest canopy can improve wildlife habitat on his property. Thus, the landowner should be aware that the capital expenditure required for a good road system is offset not only by the income gained from selling timber, but also by these future amenities which such a road system makes accessible. If the roads are not usable after logging is completed, the landowner's entire investment in the road system is lost.

LITERATURE CITED

Aubertin, G. M. and J. H. Patric. 1974. Water quality after clearcutting a small watershed in West Virginia. J. Environ. Quality 3(3); 243-249.

Hartung, R. E. and J. M. Kress. 1977. Woodlands of the Northeast: Erosion and sediment control guides. USDA SCS, Broomall and USDA FS, Upper Darby, Pennsylvania. 26p.

Lynch, J. A., E. S. Corbett, and R. Hoopes. 1977. Implications of forest management practices on the aquatic environment. Fisheries 2(2): 16-22.

Patric, J. H. 1978. Harvesting effects on soil and water in the eastern hardwood forest. Southern J. Applied For. 2(3): 66-73.

Patric, J. H. 1976. Soil erosion in the eastern forest. J. For. 74(10).

Soil Conservation Service. 1979. Soil Survey of Franklin County, Vermont. 176.

Trimble, G. R. and R. S. Sartz. 1957. How far from a stream should a logging road be located? J. For. 55(5): 339-341.

Vermont Agency of Environmental Conservation. No date. Guides for controlling soil erosion and water pollution on logging jobs in Vermont.

Wischmeier, W. H. 1972. Upslope erosion analysis. In Environmental impact on rivers. Colorado State University.

Wischmeier, W. H. and D. D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. USDA Handbook 282.

APPENDIX A

Procedure

Harvey's Lake Watershed was surveyed in June 1981. Methods used are those described previously in this report. Of 10 logging sites located, five were found to be suitable for study.

Results

No serious erosion problems were found on landings or logging roads in the watershed. Table A summarizes the findings:

Table A. Average annual erosion and sedimentation rates from logging roads and landings in Harvey's Lake Watershed.

	Erosion Rate (ton/acre/yr)			Sedimentation Rate (ton/acre/yr)		
	$\overline{X}$	S.D.	n	$\overline{X}$	S.D.	n
Overall Rate	0.9	1.33	39	0.5	0.55	9
Road Type						
Skid Trail	0.2	0.15	5	0.03	--	1
Skid Road	1.0	1.49	30	0.5	0.53	7
Landing	0.9	0.24	4	1.2	--	1
Slope Class						
0 - 5%	0.5	1.27	18	0.4	0.46	6
6 - 10%	1.6	1.71	9	0.7	0.75	3
11 - 20%	1.5	1.99	8	---	--	--
21 - 30%	0.4	----	1	---	--	--
> - 30%	---	----	--	---	--	--